A Low-Profile Patch Antenna with Monopole-Like Radiation Patterns

Mei, Peng; Zhang, Shuai; Lin, Xian Qi ; Pedersen, Gert Frølund

Published in:
Proceedings of the 2019 9th IEEE-APS Topical Conference on Antennas and Propagation in Wireless Communications, APWC 2019

DOI (link to publication from Publisher):
10.1109/APWC.2019.8870445

Publication date:
2019

Document Version
Accepted author manuscript, peer reviewed version

A Low-Profile Patch Antenna With Monopole-Like Radiation Patterns

Peng Mei
Antennas, Propagation and Millimeter-wave Systems section, Department of Electronic Systems
Aalborg University
Aalborg, Denmark
mei@es.aau.dk

Shuai Zhang
Antennas, Propagation and Millimeter-wave Systems section, Department of Electronic Systems
Aalborg University
Aalborg, Denmark
sz@es.aau.dk

Xian Qi Lin
School of Electronic Science and Engineering
University of Electronic Science and Technology of China
Chengdu, China
xqlin@uestc.edu.cn

Gert Frølund Pedersen
Antennas, Propagation and Millimeter-wave Systems sectoin, Department of Electronic Systems
Aalborg University
Aalborg, Denmark
gfp@es.aau.dk

***Abstract*— In this paper, the TM$_{22}$ mode of a square patch antenna is excited to generate a monopole-like radiation pattern. The square patch antenna is centrally fed by a coaxial probe, where four shorting pins are rigorously arranged around the feeding point to obtain good impedance match for the antenna. The simulated results demonstrate that the proposed antenna has an impedance bandwidth from 5.73 to 5.91 GHz with a total profile of 0.02λ (λ is the wavelength at 5.8 GHz), the maximal radiation direction is pointing to θ=27°, the gain and radiation patterns within the impedance bandwidth are all about 5.0dBi and monopole-like, respectively. The measured results are consistent with that of simulation.**

Keywords—high-order mode, monopole-like, conical beam, shorting pins.

I. INTRODUCTION

Monopole antennas have inherent omnidirectional radiation patterns in the horizontal plane, which are widely used in wireless communications [1]. Since the vertical monopole antenna has a relatively large height (usually λ/4), it is not recommended when a low profile or conformal geometry is desired. To realize a monopole-like radiation pattern, low profile microstrip patch antennas have been comprehensively investigated [2]-[7]. In [3], a monopole-like radiation pattern is obtained by using the TM$_{01}$ mode of a circular patch antenna; and the antenna resonates at 5.8 GHz with an overall bandwidth of 1.5% and a total profile of 0.016λ. In [7], the authors exploited periodic square patches to realize a monopole-like radiation patterns surface wave antenna; and the antenna resonates at 4.74 GHz with a 5.6% impedance bandwidth and a 5.6 dBi gain. However, the overall profile of the antenna is 3mm (approximately 0.05λ).

In this paper, a low-profile patch antenna operating in its TM$_{22}$ mode is presented. It radiates a similar pattern to a vertical monopole antenna. The antenna performance is numerically predicted and experimentally verified. The proposed antenna exhibits a great potential for wireless communication systems.

II. CONFIGURATION AND ANALYSIS

The geometry of the proposed antenna is presented in Fig.1. The antenna consists of a square radiating patch, F4B supporting dielectric substrate, and a metal ground printing on the other surface of the substrate. The dielectric substrate has a thickness of 1mm, a dielectric constant of 2.5, and a loss tangent of 0.002.

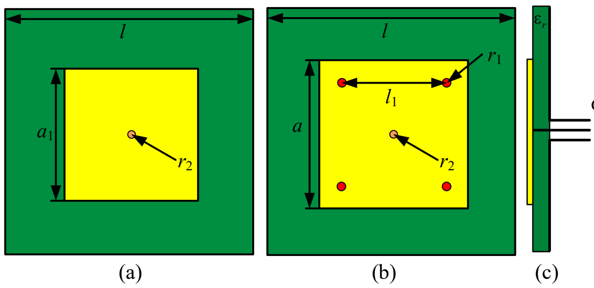
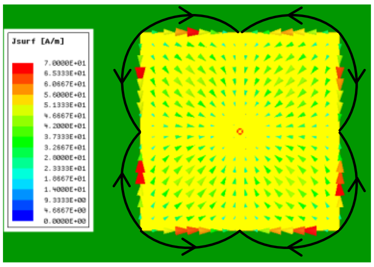


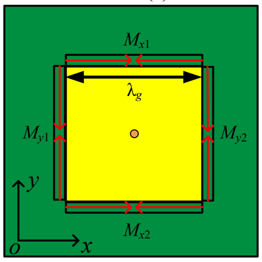
Fig. 1. The geometry of the proposed antenna. (a). Front view of antenna without shorting pins. (b). Front view of antenna with shorting pins, (c). Side view. (l=80 mm, a=34.4 mm, a_1=32 mm, l_1=22 mm, r_2=0.4 mm, r_1=0.6 mm)

A 50 Ω coaxial probe is connected to the centre of the square patch to excite the TM$_{22}$ mode as shown in Fig.1a. The surface current distribution on the square patch is plotted in Fig. 2 (a). Two half-wavelength resonant waves are observed on every edge at 5.8 GHz. Based on the field distributions on the square patch, two pairs of magnetic currents can be equivalent as shown in Fig.2 (b). Every pair of magnetic currents is served as a two-element array in x- and y-direction, respectively. The interval between these pairs of magnetic current is approximately equal to λg, where λg is the guided wavelength at 5.8 GHz. Therefore, the monopole-like radiation patterns radiating from the square patch can be predicted by superposing the far fields radiated from all these equivalent magnetic currents.

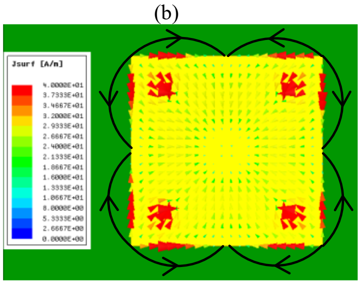
Fig. 3 gives the reflection coefficient (S$_{11}$) and input impedance of the antenna shown in Fig. 1a. It is found that the antenna has a relatively big real part at resonant frequency at 5.8 GHz, and its reflection coefficient at 5.8 GHz is just -6 dB. In order to improve the impedance match of the antenna. Four shorting pins are regularly arranged around the feeding point as shown in Fig. 1 (b). The dimensions of the square patch are also modified to make the antenna resonant at 5.8 GHz at the same time. The improved antenna with four shorting pins is shown in Fig. 1 (b). Fig. 3 also shows the reflection coefficient and input impedance of the improved antenna. It is observed that the improved antenna has a good impedance bandwidth from 5.73 to 5.91 GHz and the corresponding reflection coefficient is below -10 dB.



(a)

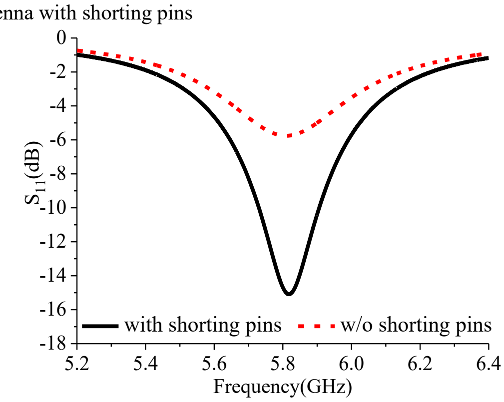


(b)

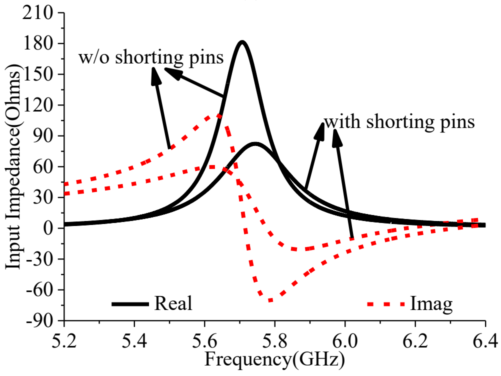


(c)

Fig. 2. Current analysis for antennas at 5.8 GHz. (a). Surface current distribution for antenna without shorting pins. (b). Equivalent magnetic currents for antenna without shorting pins. (c). Surface current distribution for antenna with shorting pins



(a)



(b)

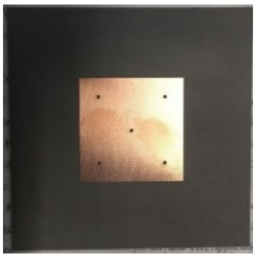
Fig. 3. Comparisons of antennas with and without shorting pins. (a). Reflection coefficient. (b). Input impedance.

The surface current distribution on the square patch with four shorting pins is also shown in Fig. 2 (c), which verifies that the current distribution on the square patch with and without shorting pins are consistent; and the presences of these four shorting pins do not change the TM_{22} mode of the antenna.

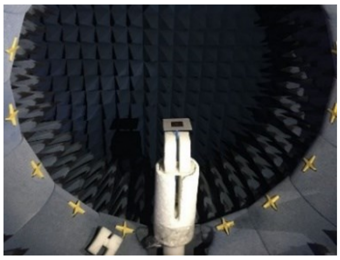
III. Simulated and Measured Results

A prototype of the proposed antenna with monopole-like radiation patterns is fabricated as shown in Fig. 4 (a). The reflection coefficient is measured using a vector network analyzer (N5244A), while radiation performances of the antenna are obtained using a Satimo Starlab System shown in Fig. 4 (b). Simulated and measured reflection coefficients are compared in Fig. 5 (a), which demonstrates a good agreement between them. The measured impedance bandwidth is 3.2 %, covering the frequency range from 5.73 to 5.92 GHz.

The realized gains and radiation efficiency of the antenna are also measured as shown in Fig. 5 (b), where the simulated counterparts are also plotted for comparison. Within the -10 dB frequency band (5.73-5.92 GHz), the measured peak gain reaches 5.05 dBi, with a gain variation of less than 0.3 dB. The measured radiation efficiency ranges from 78.1 % to 88.1 %.

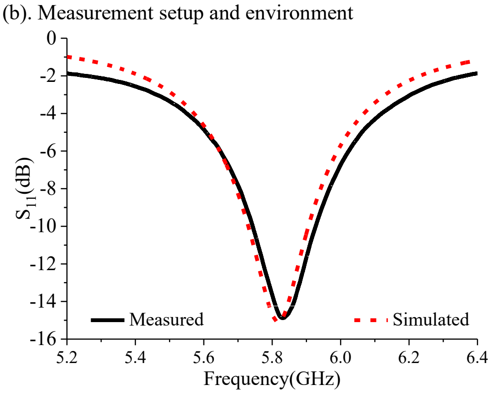


(a)

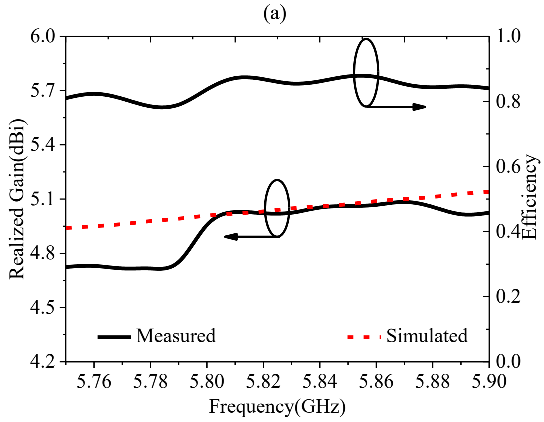


(b)

Fig.4. Photographs for antenna and measurement setup. (a). Fabricated antenna. (b). Measurement setup and environment



(a)



(b)

Fig.5. Simulated and measured results. (a). Reflection coefficient (S_{11}), (b). Realized gain and efficiency

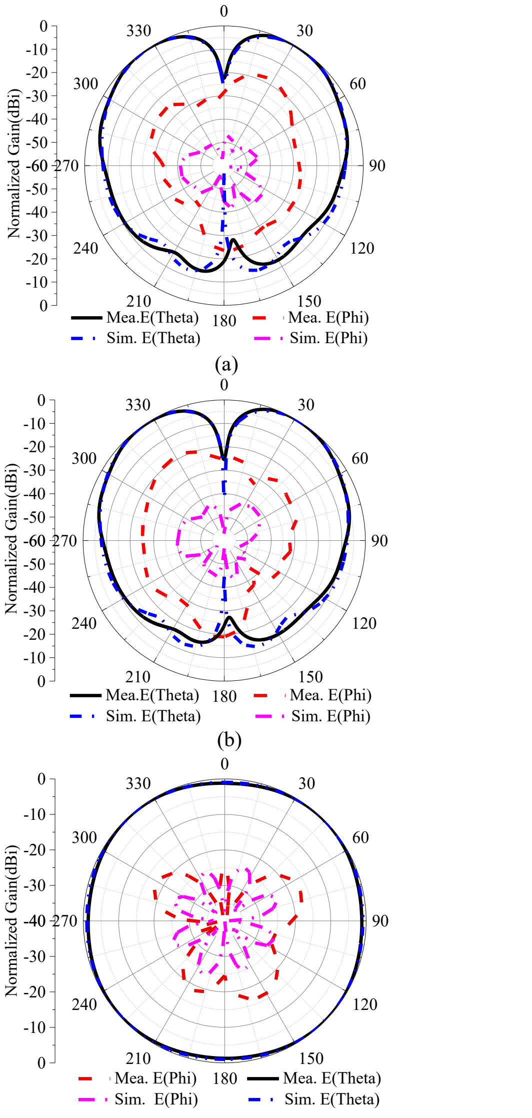


Fig.6. Simulated and measured radiation patterns. (a). *φ=0º*. (b). *φ=45º*. (c). *θ=27º*

The radiation patterns of the fabricated antenna are measured at the resonant frequency of 5.8 GHz and plotted in Fig. 6. The measured radiation patterns agree well with the simulated ones, and a monopole-like pattern is obtained. Both the *xoz* plane (φ=0º) and diagonal plane (φ=45º) patterns are presented. It has a deep null in the broad side direction and the antenna beam is at θ=27º direction with a maximal gain of 5.0 dBi. The co-polarization and cro-polarization are along the θ and φ direction, respectively, and the measured co-polarization is -20 dB lower than the co-polarization in the front side. Moreover, the radiation pattern in the azimuth plane (θ=27º) for the antenna working at 5.8 GHz is also measured as shown in Fig. 6 (c). In the azimuth plane (θ=27º), the antenna generates an omnidirectional radiation pattern with a ripple of less than 0.8 dB, and the overall measured cro-polarization level is lower than -20 dB in the azimuth plane (θ=27º). Moreover, the measured radiation patterns of the proposed antenna demonstrate a monopole-like shape at 5.75 GHz, 5.85 GHz, and 5.90 GHz, respectively. For sake of brevity, they are not presented in the paper. It is indicated that the proposed antenna has invariable monopole-like radiation patterns within the impedance bandwidth.

IV. Conclusion

A low-profile patch antenna with monopole-like radiation patterns is proposed, designed, fabricated, and measured. A 50 Ω coaxial probe is connected to the centre of the square patch to excite the TM_{22} mode, resulting in a monopole-like radiation pattern. In order to obtain a great impedance bandwidth, four shorting pins are regularly arranged around the feeding point. The experimental results demonstrate an impedance bandwidth of 3.2 % from 5.73 to 5.92 GHz (S11<-10 dB). The measured radiation patterns in the xoz plane (φ=0º) and diagonal plane (φ=45º) at 5.8 GHz are almost identical, and its maximum beam is around 27º from the z axis (θ=27º). The overall profile of the antenna is just 1mm, which is less than 0.02λ. The low-profile patch antenna with monopole-like radiation pattern could be an excellent candidate for modern wireless communication systems such as radio receivers on the vehicles.

Acknowledgment

This work was supported in part by NSFC (No. 61571084), in part by EPRF (No. 6141B06120101), in part by NDSTI (No. 1716313ZT00802902), in part by NKIF (No. 2017510007000006), in part by the project of “the InnovationFonden Project of MARS2”.

References

[1] W. L. Stutzman, and G. A. Thiele, Antenna Theory and Design, 2nd ed. New York: Wiley, 1998.

[2] J. Huang, “Circularly polarized conical patterns from circular microstrip antennas,” IEEE Trans. Antennas Propag., vol. 32, pp. 991-994, Sep. 1984.

[3] L. Economou, and R. J. Langley, “Patch antenna equivalent to simple monopole,” Electron. Lett., vol. 33, no. 9, pp.727-729, Nov. 1999.

[4] C. B. Ravipati, “Compact circular microstrip antenna for conical pattern,” in Proc. IEEE AP-S Int. Symp. Dig., Jun. 2004, vol. 4, pp.3820-3823.

[5] C. B. Ravipati, D. R. Jackson, and H. Xu, “Center-fed microstrip antenna with shorting vias for miniaturization,” in Proc. IEEE AP-S Int. Symp. Dig., Jul. 2005, vol. 3B, pp.281-284.

[6] A. Al-Zoubi, F. Yang, and A. Kishk, “A low profile dual band surface wave antenna with a monopole-like pattern,” IEEE Trans. Antennas Propag., vol. 55, pp. 3404-3412, Dec. 2007.

[7] F. Yang, Y. Rahmat-Samii, and A. Kishk, “Low-profile patch-fed surface wave antenna with a monopole-like radiation pattern,” IET Microw. Antennas Propag., vol. 1, no. 1, pp. 261-266, Feb 2007.